# Multiscale simulations for flows in heterogeneous porous media

Thomas Y. Hou
Applied Mathematics
Caltech, Pasadena, CA 91125

*Abstract*

Numerical simulation of dynamic flow, and transport processes in natural geologic formations is the primary computational tool for the management of natural resources, including oil reservoirs. The development of algorithms for modeling these dynamic multi-physics processes in large-scale highly heterogeneous formations is very challenging because the properties of natural geologic porous formations (e.g., permeability) display high variability levels and complex spatial correlation structures, which span a rich hierarchy of length scales. Thus, it is usually necessary to resolve a wide range of length and time scales in order to obtain accurate predictions of the flow, mechanical deformation, and transport processes under investigation. In practice, however, some type of coarsening (or upscaling) of the detailed geologic model is usually performed before the model can be used to simulate complex displacement processes. Many approaches have been developed and applied successfully when a scale separation adequately describes the spatial variability of the subsurface properties (e.g., permeability) that have bounded variations. The quality of these approaches deteriorates for complex heterogeneities, especially when the contrast in the media properties is large, e.g., in the case of fractured porous media. The challenging problem is to develop a methodology that can capture the nonlocal effects accurately for heterogeneous systems with multiple spatial and temporal scales and high jumps in the media properties.

In this talk, we will discuss our research activities on designing accurate multiscale simulation techniques that allow a sparse representation of the solution on a coarse grid. We seek a coarse-scale representation of the solution by incorporating important local features of the solution into multiscale basis functions. These basis functions are further coupled on a coarse grid using a variational formulation. Accuracy of multiscale methods is very sensitive to spatial variations of local heterogeneities and the contrast in the coefficients. We will discuss how high-contrast in the conductivity field affects the accuracy of multiscale simulations. To resolve this difficulty, we propose a new class of basis functions that allow us to achieve optimal accuracy when permeability field has high-contrast inclusions.

When media properties contain high-conductivity channels, additional basis functions are needed to represent disconnected channelized features. To maintain a sparse representation of the solution, it is important to carefully select these basis functions that represent long-range information, while keeping the dimension of the coarse space small. This is accomplished in two steps. The first step is to construct an initial coarse space to give a sparse representation of the multiscale solution. It is important to keep the dimension of the initial coarse space to be as small as possible. Our initial coarse space has only one degree per node. In the second step, we propose a new local spectral problem. This local spectral problem is used to identify additional basis functions that represent long-range information. We then supplement the initial coarse space with these new bases. The enrichment of the initial coarse space with these new bases guarantees that we take into account the long-range information component of the solution. We will also show that when these basis functions are used to construct the domain decomposition preconditioners, the resulting preconditioners are optimal with respect to the physical parameters, such as small spatial scales and high-contrast in the coefficients. Numerical results will be presented. The talk will be based on our joint works with L. Durlofsky (Stanford), Y. Efendiev (Texas A& M), H. Tchelepi (Stanford), and our other collaborators. This work is supported by DOE.